
Standardizing the Next Generation of Military Vehicle Cooling System Simulation

Mary Goryca, US Army Tank-Automotive Research,
Development and Engineering Center

Neil Slyva, Flowmaster USA



Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 26 OCT 2006		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Standardizing the Next Generation of Military Vehicle Cooling System Simulation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Goryca, Mary Slyva, Neil				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) USATACOM 6501 E 11 Mile Rd Warren, MI 48397-5000				8. PERFORMING ORGANIZATION REPORT NUMBER 16651	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S) TACOM TARDEC	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) 16651	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 25	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Agenda

- Process overview
- Current approach to system validation
- Alternative method to system validation
- Method validation process
- Results
- Next Steps

Process Overview

CURRENT APPROACH	ALTERNATE METHOD	VISION	PILOT PROJECT	STRATEGY
<ul style="list-style-type: none"> • To measuring the adequacy of military cooling systems is to conduct vehicle Full Load Cooling tests 	<ul style="list-style-type: none"> • Complement the testing process • Informed decisions • Minimize Testing • Maximize Test Results 	<ul style="list-style-type: none"> • Develop and integrate a powertrain cooling simulation capability 	<ul style="list-style-type: none"> • MTV • PIP • Improve cooling • Conduct FLC Test • Capture data 	<ul style="list-style-type: none"> • Create a FLC simulation • Based on vehicle test data • predict critical fluid temps.
<ul style="list-style-type: none"> • Production vehicles • Controlled laboratory environment • Simulating field operating conditions 	<ul style="list-style-type: none"> • Provide the ability to do quick what ifs • Save time • Reduce costs 	<ul style="list-style-type: none"> • Selected a 1D fluid flow analysis commercial software to build the FLC simulation tool. 	<ul style="list-style-type: none"> • 6x6 Truck • Multiple variants • Common Chassis 	<ul style="list-style-type: none"> • Validate • Compare results • Check accuracy

Current Approach

Products Tested

Complete Vehicles

Combat
Tactical

Powertrains
Engines
Transmissions
& Components

Radiators
Air Cleaners
Grilles
Roadwheels/
Tires



Testing Services

Qualification/Acceptance

Performance/Durability

Research/Development

Evaluation of Field Problems

Product Improvement Programs



Test Capabilities

Vehicle Tests

Full Load Cooling
Fuel Consumption
Heat Soak

Performance Tests

Engine
Transmission
Radiator
Air Filter



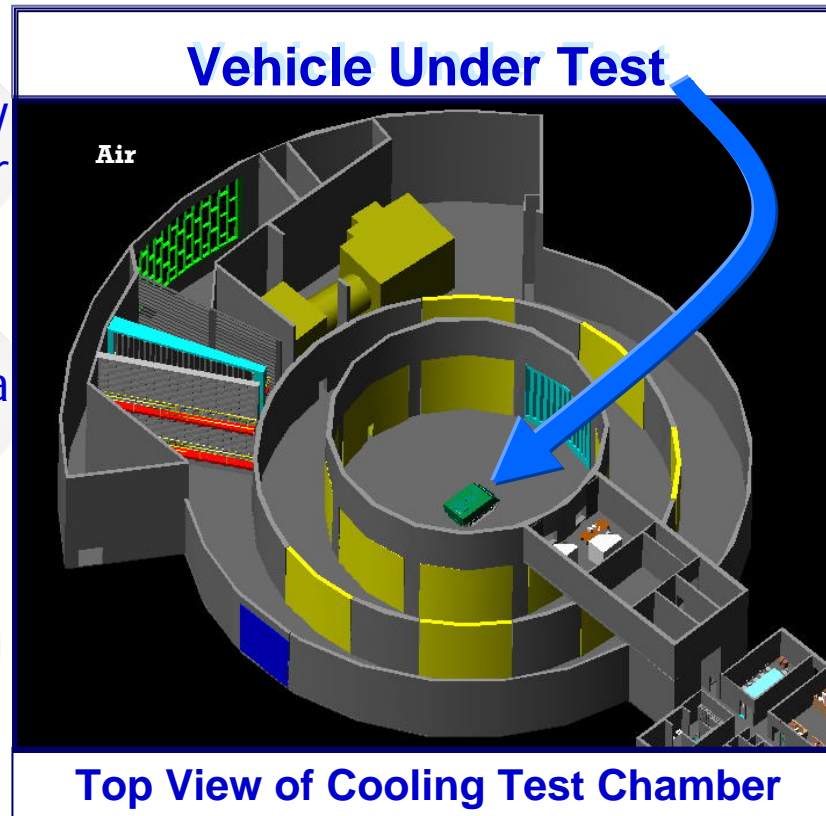
Current Approach

Powertrain cooling tests conducted on tactical & tracked vehicles

Unique environmentally
controlled test chamber

50 ft high x 80 ft in dia

Ambient Air up to 160°F



Solar Radiation
355 Btu/hr-ft²

Dynamometer
Absorption up to
70,000 ft-lb per side

Air Flows \leq 20 mph

Monitor critical temps to ensure they are within allowable limits.

Current Approach

Two main tests
evaluate vehicle
cooling systems

FULL LOAD

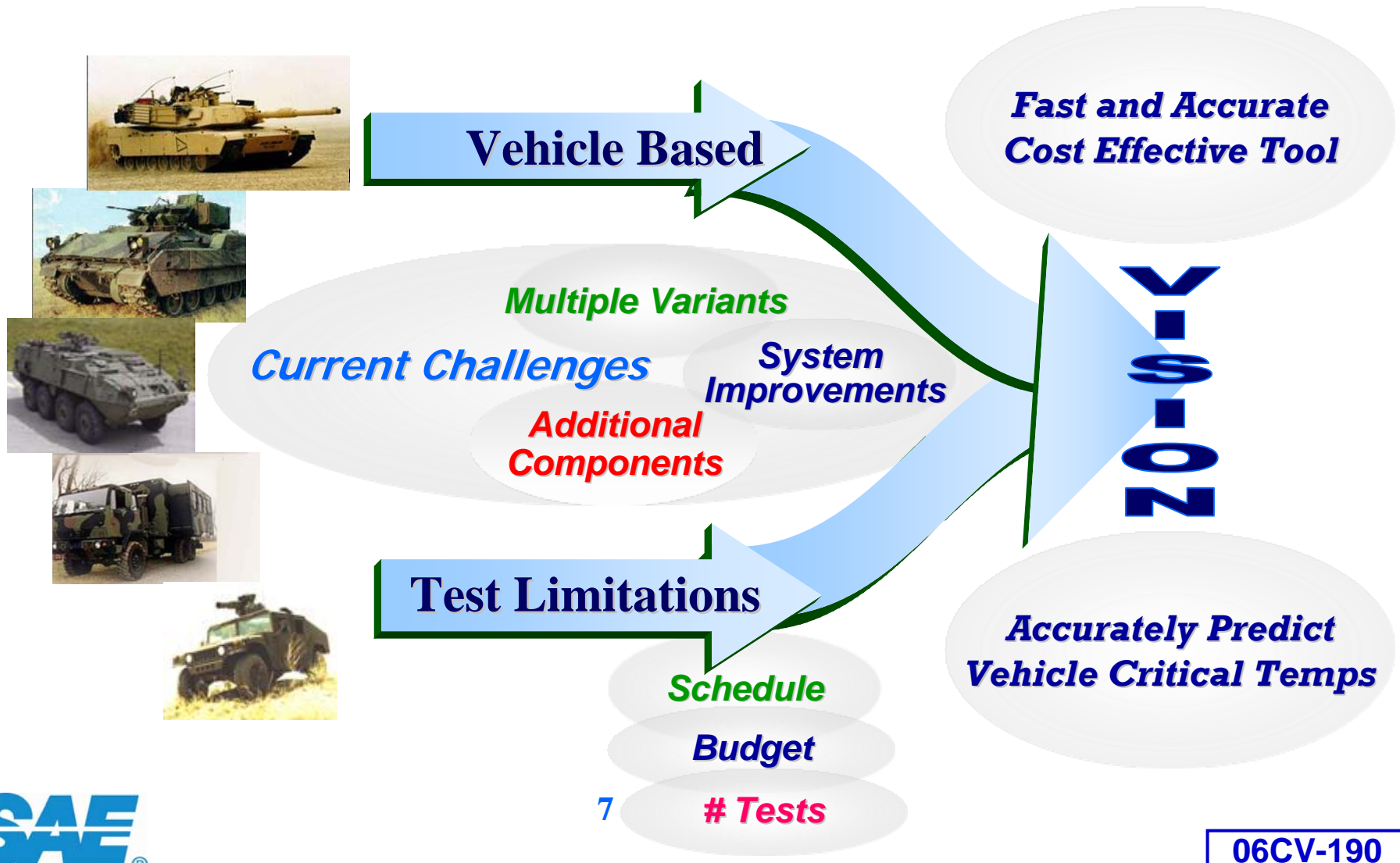
Ambient Air = 120°F
High Load
Low Engine Speed
Coolant = 50/50
Ethylene Glycol/H₂O



FULL POWER

Ambient Air = 120°F
Low Load
Max. Engine Speed
Coolant = 50/50
Ethylene Glycol/H₂O

Alternative Method



Alternative Method

Software Criteria

- User friendly, fast and accurate
- Cooling components advanced and ready to use
- Simultaneous solving of component solutions
- 3D visualizing capability
- Cost effective
- Fully supported and routinely updated
- Steady state and transient capabilities

Pilot Project - Medium Tactical Vehicles



M1087 Expandable Van



M1093 Cargo Truck



M1098 Wrecker



M1090 Dump Truck



Common Chassis

Commonality

Chassis

Drive Train

Spare Parts

Tools

Differences

Payloads

Mission Requirements

TAC Design

TAC Location



Material Handling Equipment



Load Handling System

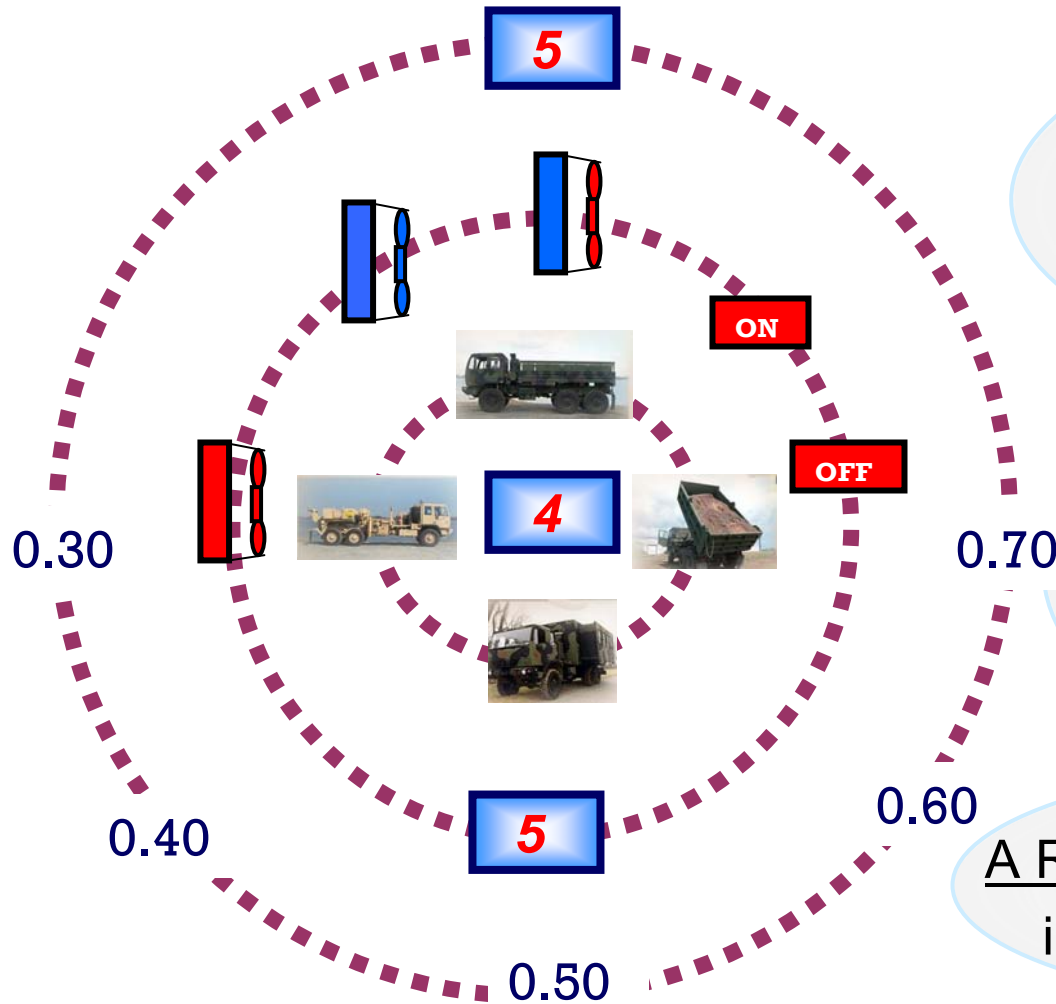


MTV



M1088A1 Tractor

Pilot Project – MTV Test Matrix



Several Configurations:

Radiator/Fan (Base/Replacement)

Air Conditioning (on/off)

Multiple Variants

Cargo

X-Van

Wrecker

Dump

A Range of Tractive Effort/Weights
in high ambient temperatures

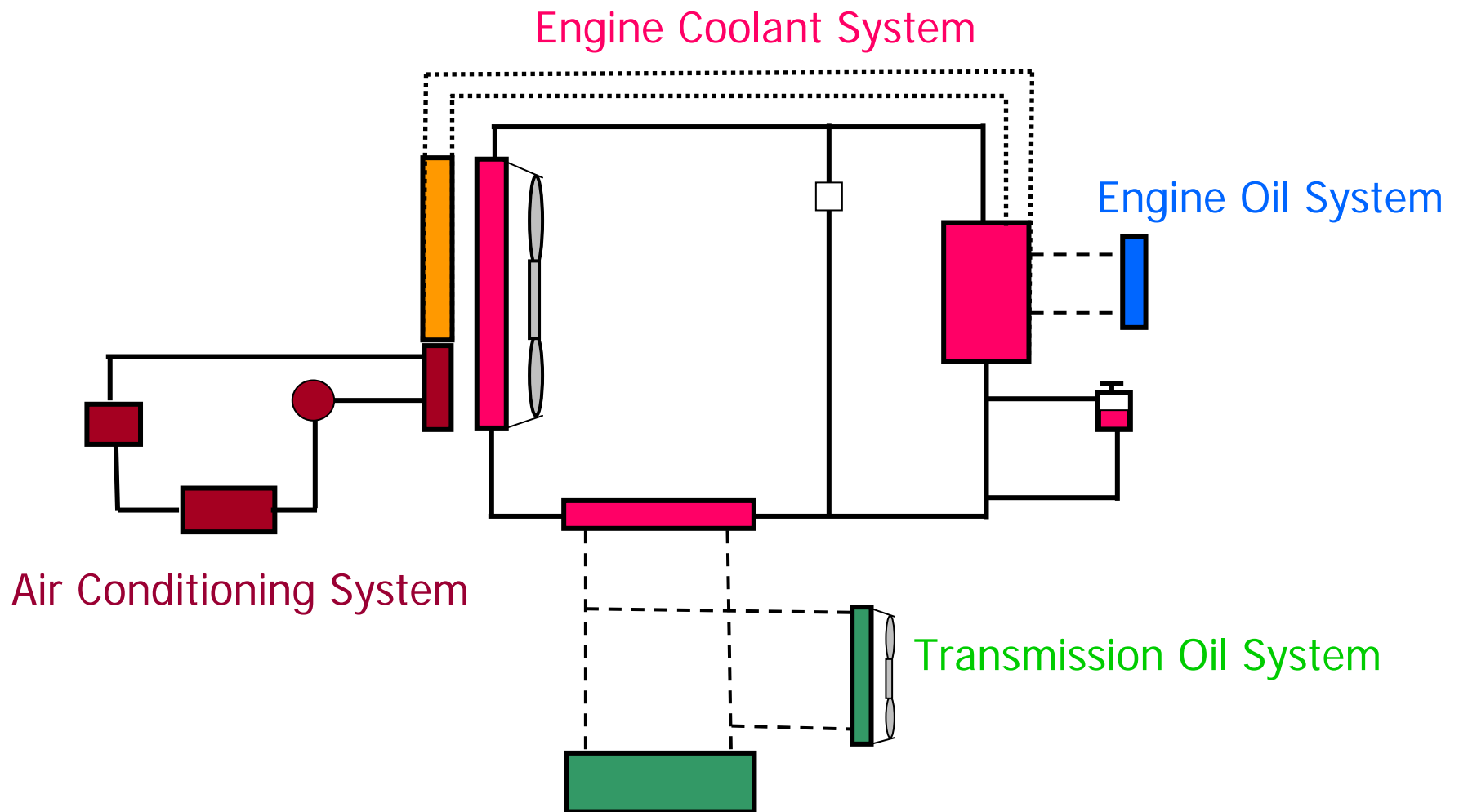
Conventional methods only allowed 40% of the desired results to be captured within this test matrix.

Full Load Cooling System Simulation Objectives

- ≡ Create a FLC system simulation based on vehicle test data that predicts critical fluid temperatures.
- ≡ Validate and compare simulation results with test results
- ≡ Use simulation to complement testing.

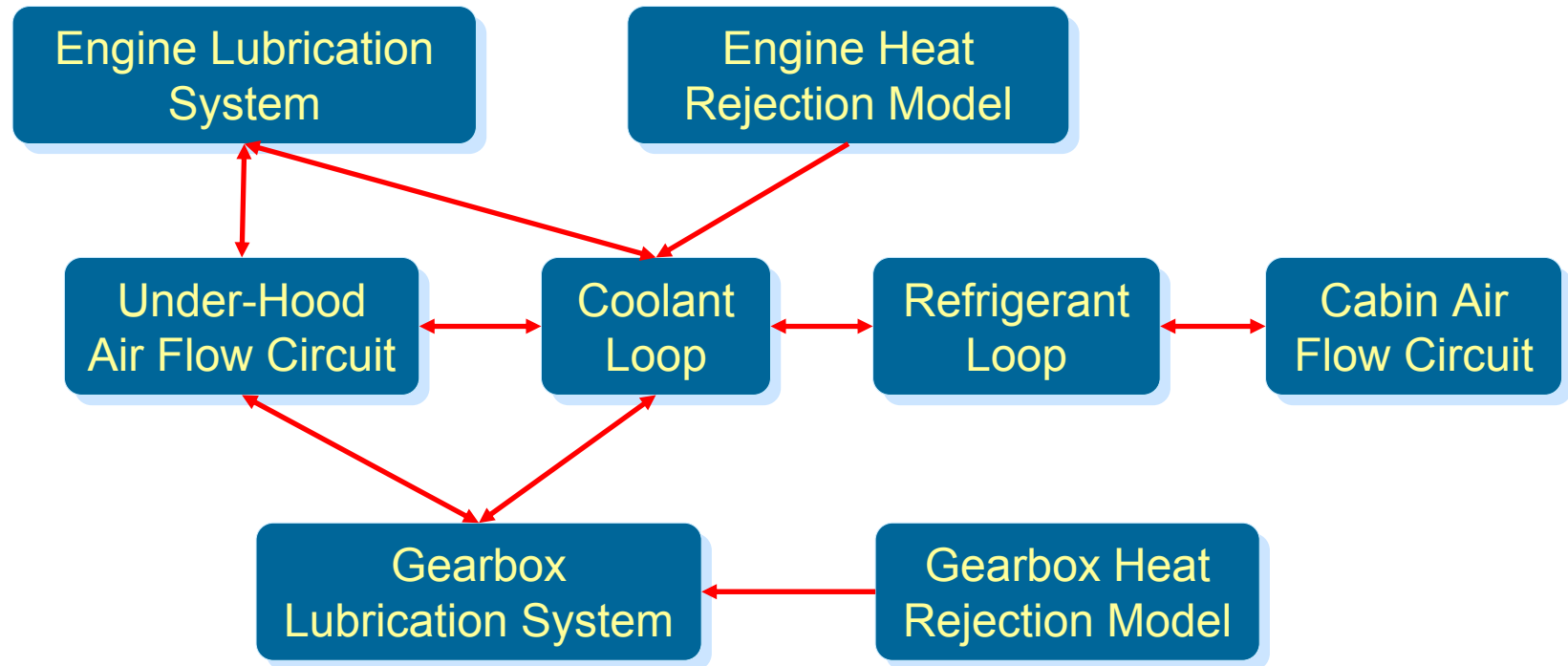
Full Load Cooling System Simulation

FMTV Fluid and Thermal Systems

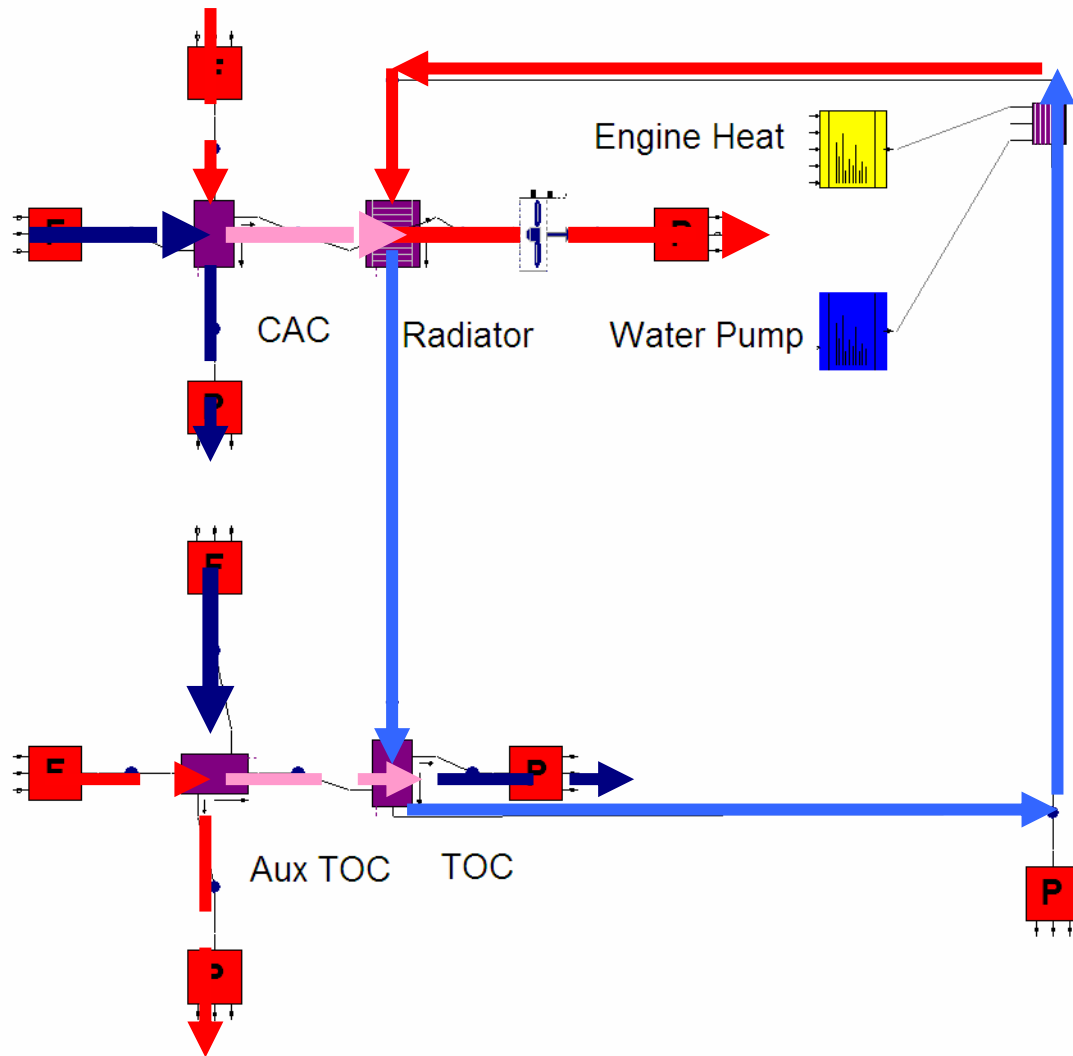


Full Load Cooling System Simulation Responsibilities

Thermal system interaction:

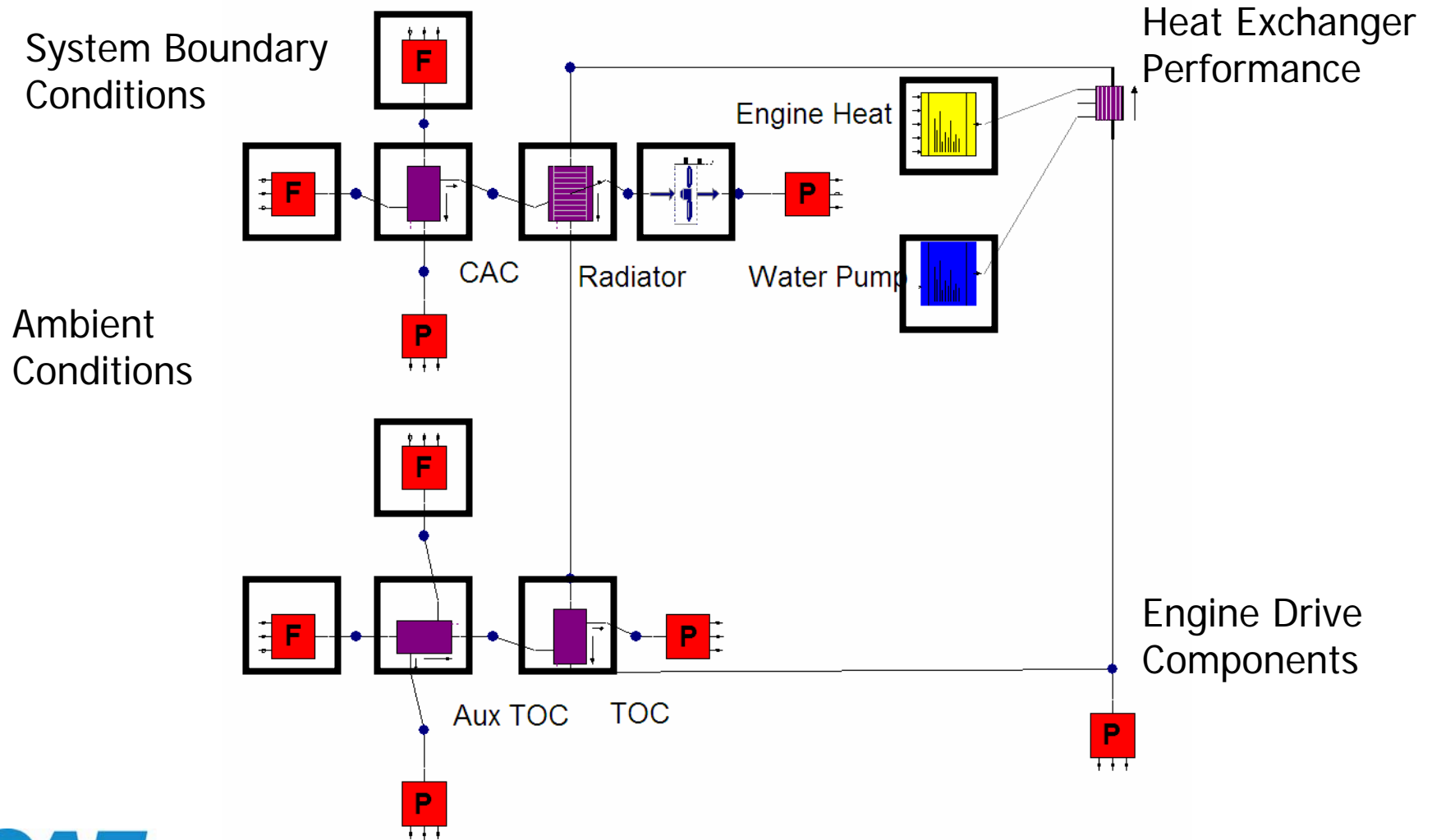


Full Load Cooling System Simulation 1-D System Model Set Up



Full Load Cooling System Simulation 1-D

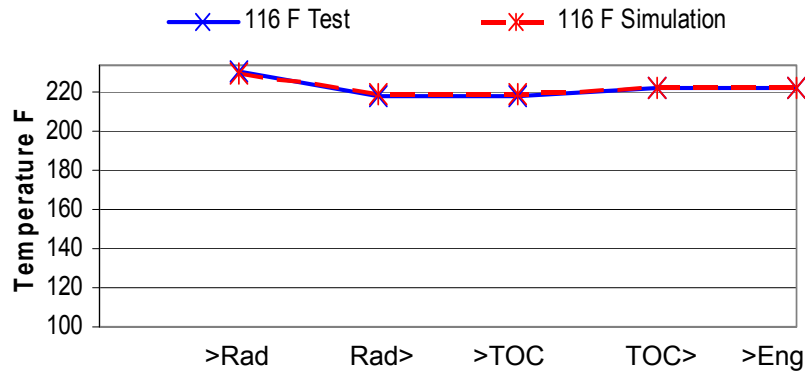
System Model Inputs



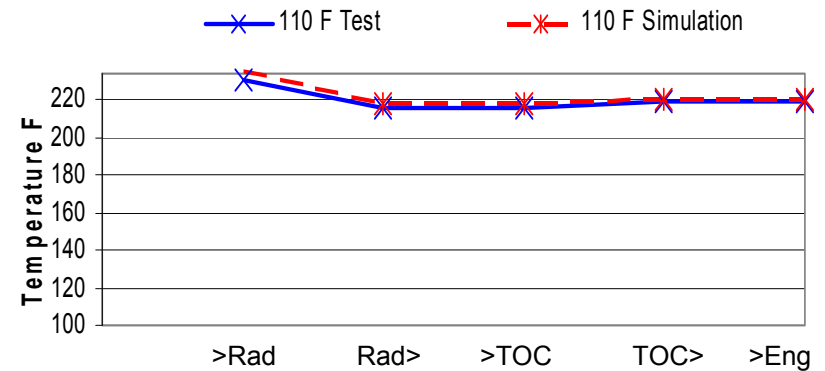
Full Load Cooling System Simulation Comparison with Test

Full Load Cooling System Simulation - Coolant Temperatures

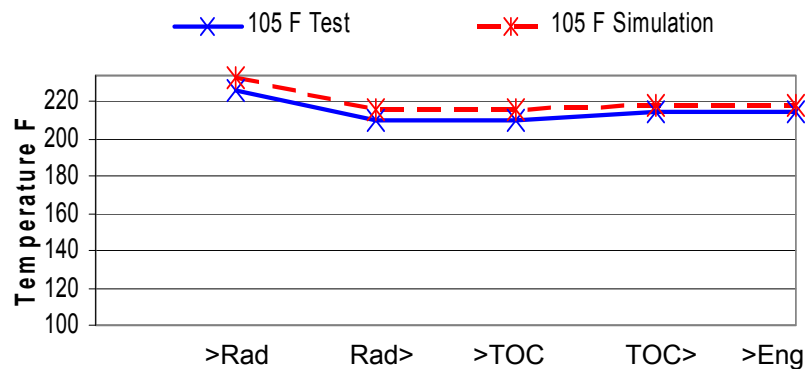
Coolant Temp at 0.6 TE/WT - Vehicle #1



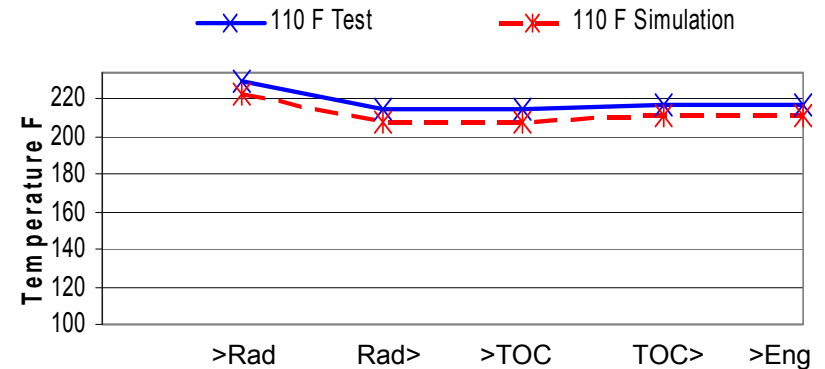
Coolant Temp at 0.55 TE/WT - Vehicle #2



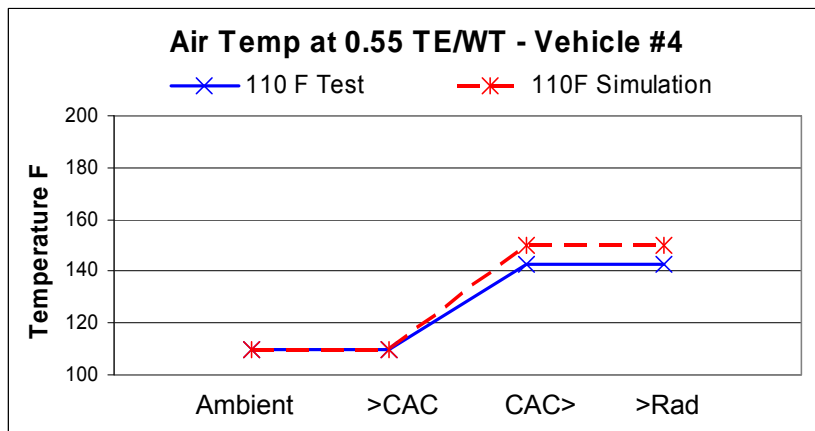
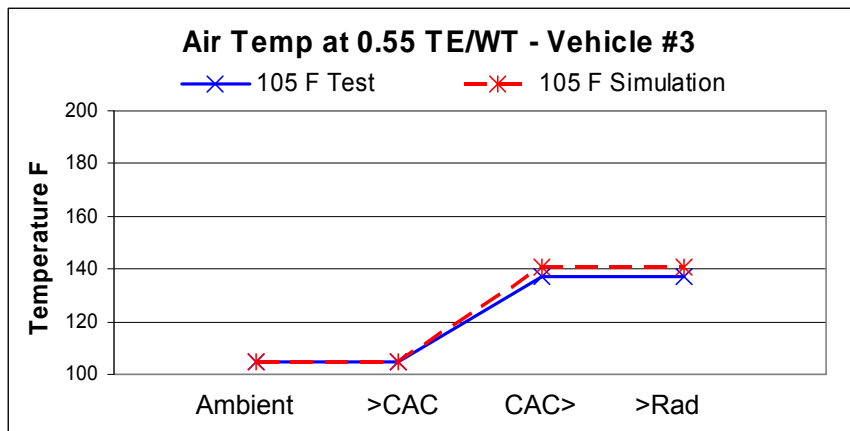
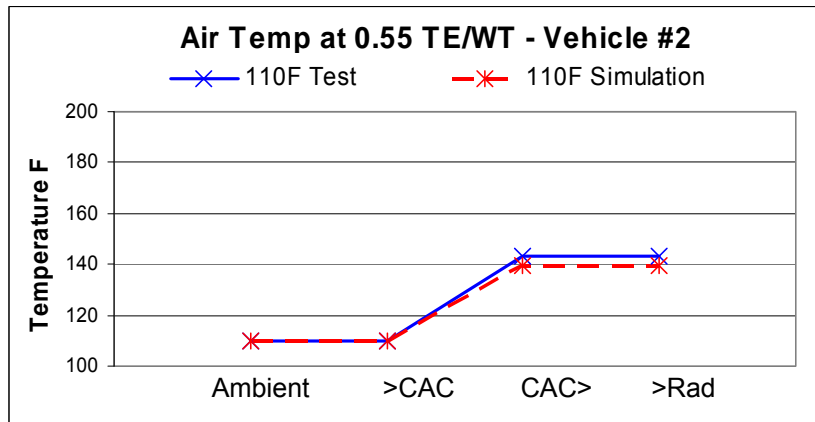
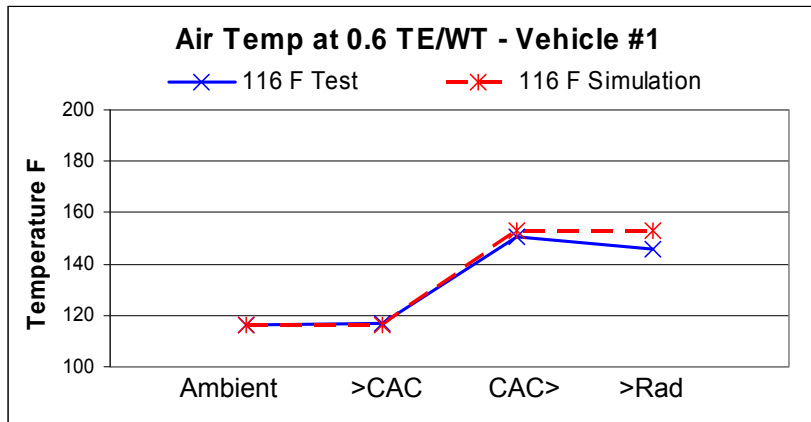
Coolant Temp at 0.55 TE/WT - Vehicle #3



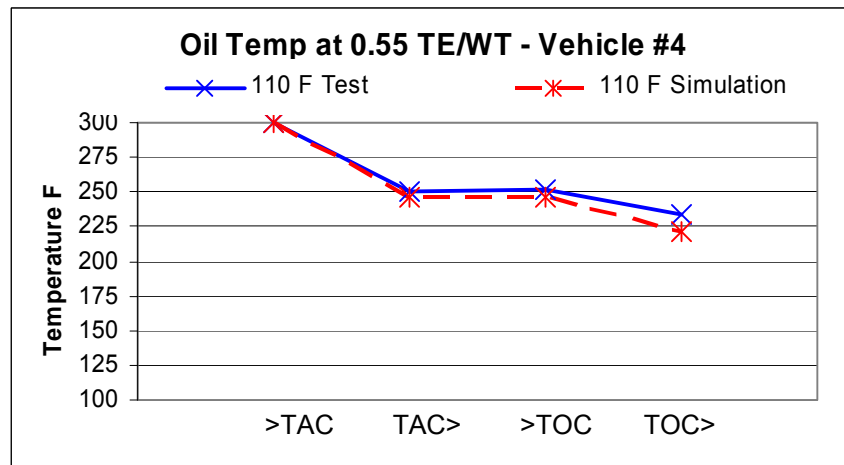
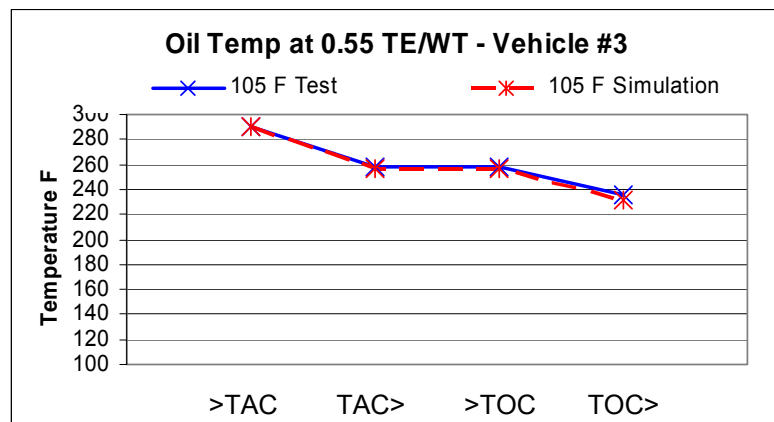
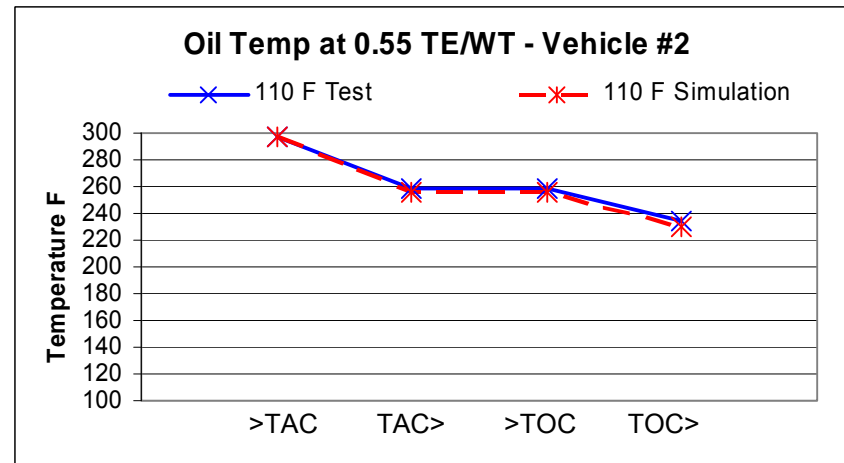
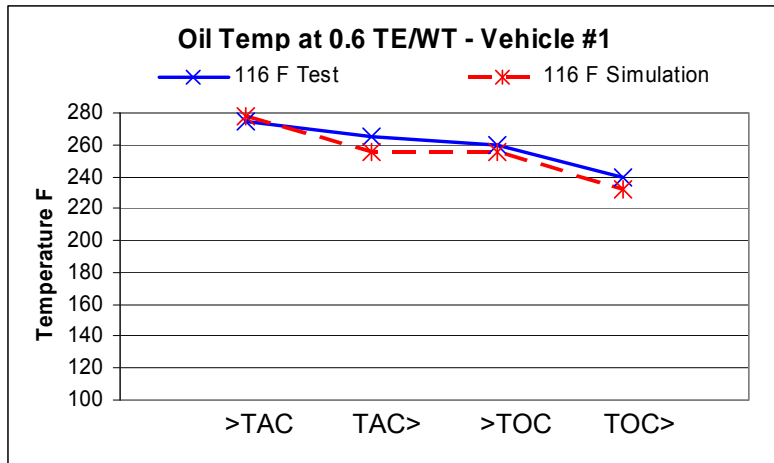
Coolant Temp at 0.55 TE/WT - Vehicle #4



Full Load Cooling System Simulation – Air Temperatures

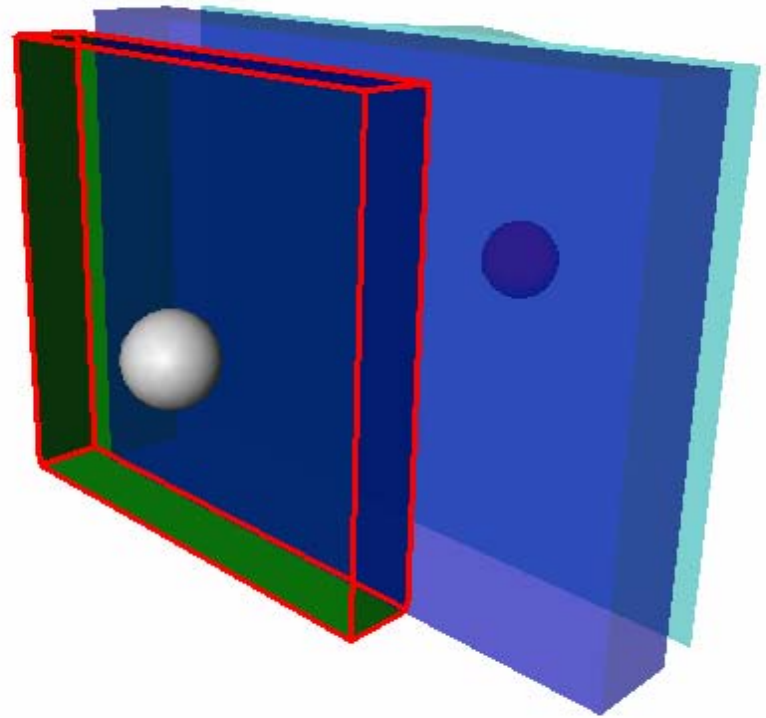


Full Load Cooling System Simulation- Oil Temperatures



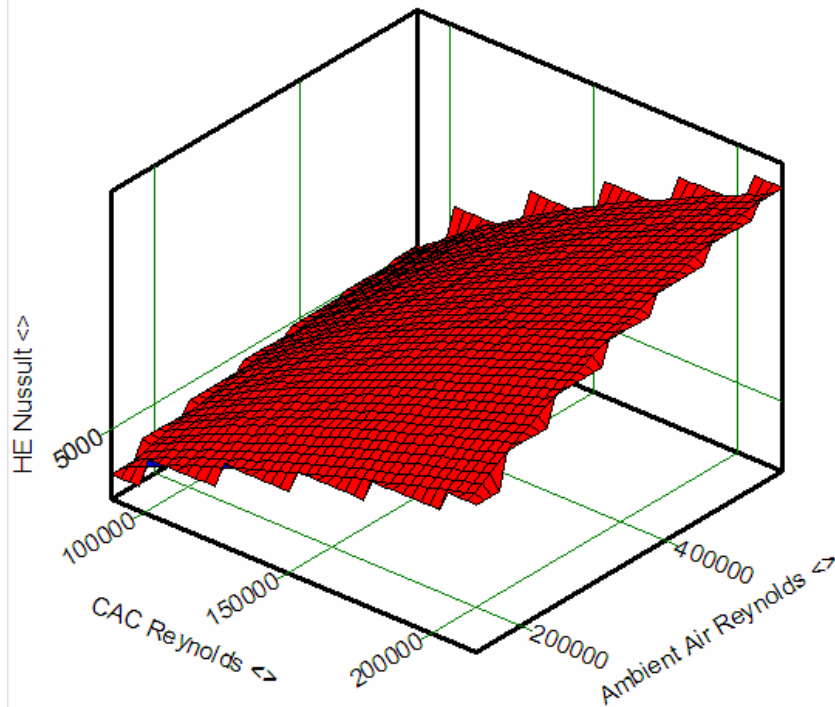
Next Steps – Additional Variables

- Performance
 - Equal or better than existing exchanger under same operating conditions
- Variable Geometry
 - Height, width, and depth
- Variable Location

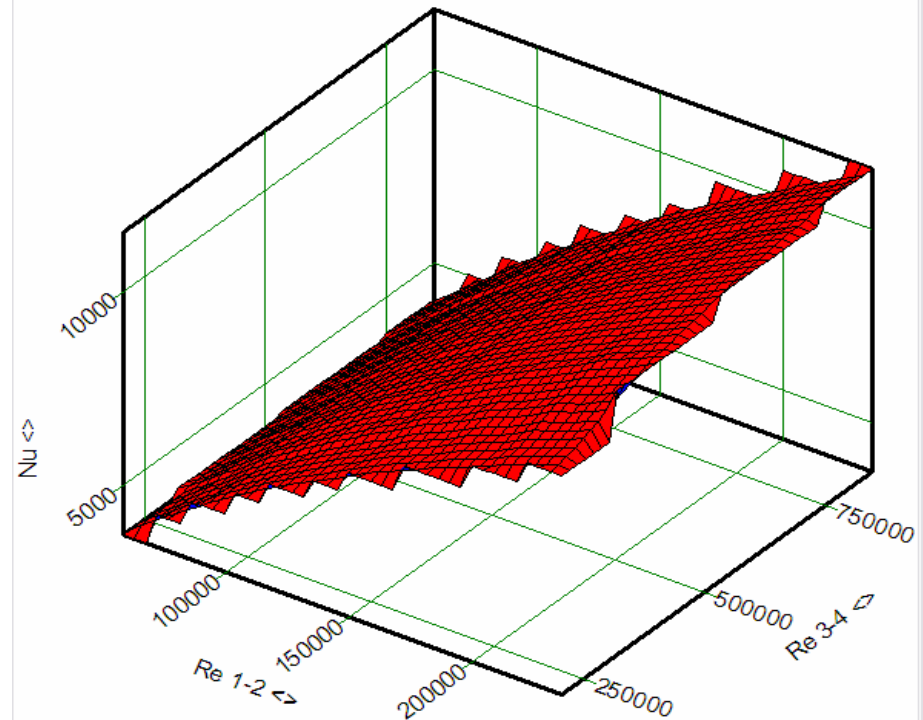


Next Steps - Performance Characteristics

Charge Air Cooler Nusselt Number vs. Re₁₂ vs Re₃₄ V3



CAC Nu v Re₁₋₂ v Re₃₋₄



Next Steps – Automated Approach

Nusselt Number Calculator V5.user.xls

Flowmaster Nusselt Number Calculator

Project and Component Location

Database Folder: C:\Flowmaster_Databases\65Database\flows_db Pipe Area 1: 1 m²

Project Folder: C:\Flowmaster_Databases\65Database\flows_ud Pipe Area 2: 1 m²

Project Name: AVS_112305 Width Across Air: 1 m

Network Name: AVS_Example Thickness in Air F: 1 m

Surface Title: Run_FM_Macro_Test Vertical Height: 1 m

Heat Exchanger Properties

Thickness (m): 0.016

Hot Side

Fluid Type: Glycol/Water 50/50

Flow Area (m²): 1.12E-03

Hydraulic Diameter (m): 0.001825

Inlet Pressure (bar): 1

Air Side

Fluid Type: Dry Air as real gas

Flow Area (m²): 0.3312

Hydraulic Diameter (m): 0.001

Inlet Pressure (bar): 1.013

Required Calculation Steps

- 1) Enter 'Database Dir.' and 'Project Dir.'
- 2) Enter Project Name and 'Netv'
- 3) Enter 'Measured Data'
- 4) Click button 1 (to read database fluids)
- 5) Select required fluids from dropdown menus
- 6) Click button 2 to calculate Nusselt Number
- 7) Enter in "Surface Title"
- 8) Click button 3 to add your surface to FM
- 9) Click button 4 to run FM analysis and view results

Results

Temperature (°C): Heat Duty (kW):

Note: Highlighted cells in this column indicate values that have been limited to prevent errors.

Required Data

Mass Flow Rate (kg/s): T_{in} (°C): T_{out} (°C): Heat Duty (W):

Optional Data (give T or Duty)

Data Retrieved from FLOWMASTER2

Hot Side: Specific Heat (J/kg K): η (N s/m²):

Air Side: Specific Heat (J/kg K): Thermal Cond. (W/m² K): Viscosity (N s/m²):

Calculated Results

ΔT_i : (m c_p)_h: (m c_p)_c: q (W/m²): ΔT_c : U (W/m² K): Re_h: Re_c: Nu

24	0.328833333	0.80711904	80.8	29.4	59.571871	59.840333	24815.648	3554.980914	0.0012206	1010.039783	0.027384644	1.93E-05	51.4	1169	815.222	0.4123994	3553.1914	454.8111	126.25494	2076.0198
25	1.619166667	0.806242	80.8	27.3	75.123978	67.756308	32953.064	3585.559626	0.0010367	1010.283968	0.027583045	1.943E-05	53.5	5805.62	814.533	0.1060947	3950.6894	2636.7653	125.3032	2291.6626
26	0.856	0.81659556	80.9	29	67.931551	65.84128	30392.572	3572.366132	0.001074	1010.236486	0.027579523	1.943E-05	51.9	2343.47	824.959	0.2498851	4227.1854	1000.0325	126.92409	2452.3617
27	0.978666667	0.80928386	81.5	29.8	72.557379	68.114139	31350.352	3582.072836	0.0010552	1010.34998	0.027689636	1.949E-05	51.7	3505.66	817.66	0.1729747	4156.0665	1565.8475	125.34723	2401.7498
28	0.328166667	1.39118	80.7	30.4	53.057391	53.258087	32114.024	3540.128819	0.0013388	1009.928858	0.027181968	1.917E-05	50.3	1161.75	1404.93	0.5495576	4563.7901	413.81851	219.08174	2689.895
29	0.3275	1.98193964	80.9	30.1	49.80532	48.075186	35975.58	3532.702244	0.001086	1009.819927	0.0269829	1.904E-05	50.8	1156.36	2001.4	0.6121047	4791.1177	392.51898	314.21815	2840.9902
30	1.955666667	0.77084698	80.4	27.3	75.635034	70.202935	33415.2	3585.809304	0.0010351	1010.38778	0.027666399	1.948E-05	53.1	7012.65	778.854	0.0897362	4407.731	3189.5969	119.47813	2549.0738
31	1.2935	0.80454555	81.4	30.6	74.424703	70.39116	32348.76	3585.284369	0.0010387	1010.461329	0.027792626	1.956E-05	50.8	4637.57	812.362	0.1373105	4537.863	2102.3381	124.18608	2612.4127
32	0.656333333	1.3817892	81.3	28.3	63.889882	57.489333	40735.632	3564.90976	0.0010545	1009.971201	0.027259348	1.922E-05	53	2339.77	1395.57	0.3284931	4641.801	959.78362	217.05134	2724.5265
33	0.9755	1.36794319	81.9	28.1	69.283905	59.959672	44018.772	3576.578866	0.0010857	1010.016307	0.027341778	1.927E-05	53.8	3488.95	1381.64	0.2345096	4686.51	1516.9122	214.28768	2742.4757
34	0.328166667	3.16297245	82.7	31.7	47.533093	44.455106	40738.609	3529.981562	0.0014522	1009.779793	0.026909557	1.9E-05	51	1158.42	3193.91	0.6895553	5324.2238	38149083	502.70025	3165.6999
35	0.6555	1.98366702	81.7	28.5	61.215202	52.362371	47802.363	3593.95327	0.001894	1009.873315	0.027080464	1.911E-05	53.2	2333.55	2003.25	0.3880532	5054.1246	930.42723	313.4632	2986.1377
36	0.328833333	4	80	30	42.008433	40.86241	43870	3511.534437	0.0016231	1009.674641	0.026717394	1.887E-05	50	1154.71	4038.7	0.7598447	6389.5434	340.77213	639.87807	3826.4471
37	1.293333333	1.39406945	81.4	29.9	71.061732	63.883613	47857.436	3579.147077	0.0010705	1010.171302	0.027545504	1.94E-05	51.5	4629.03	1408.25	0.2007484	5671.942	2039.7257	216.91737	3294.5875
38	1.294333333	1.9960106	80.8	27.9	68.319028	56.525413	57721.898	3572.958934	0.001037	1009.944103	0.027209828	1.919E-05	52.9	4624.16	2016.46	0.2359455	5846.2369	1979.8456	314.14449	3437.7208
39	0.975833333	1.95521414	82.4	31.9	67.05739	58.966256	53492.877	3573.039558	0.001075	1010.072463	0.027444403	1.934E-05	50.5	3486.69	1974.91	0.3038023	6080.8063	1487.5121	305.24218	3545.0908
40	1.6215	1.99142342	80.5	27.5	70.209138	57.173468	59680.373	3576.093092	0.0010854	1009.949031	0.027218834	1.92E-05	53	5798.63	2011.24	0.1941914	5915.6704	2522.18	313.23561	3477.3982
41	0.657833333	3.21264189	81.9	31.4	57.617706	48.890833	56745.95	3552.450401	0.0012453	1009.86196	0.027059713	1.909E-05	50.5	2336.92	3244.32	0.4808389	6259.6702	891.80483	508.02185	3701.2485

Master Copy

Next Steps - Results

Top Tank Temperatures

	Vehicle A	Vehicle B	Vehicle C
Heat Exchangers			
X	180 °F	200 °F	210 °F
Y	180 °F	200 °F	210 °F
Z	180 °F	200 °F	210 °F

Next Steps - Observations

- Simulation accurately represents cooling system performance
- Thermal simulation simplified complex interactions
- Initial validation process utilized:
 - Pre-processed component test data
 - Comprehensive vehicle test data
- Process enables rapid and accurate analysis
 - Heat exchanger options
 - Multiple vehicle variants
- Validating process for future heat exchanger evaluation

Thanks for attending!

Questions?

Mary Goryca, US Army Tank-Automotive Research,
Development and Engineering Center

Neil Slyva, Flowmaster USA

